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USGS Cooperative Agreement for Geodetic Monitoring Operations

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Geodetic Monitoring Project Name:
Continued Operation of the Pacific Northwest Geodetic Array

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Major Goal(s) & Activities of the Geodetic Project:

Throughout the duration of this award we've made considerable progress expanding the structure and operation of PANGA, its daily and real-time data analyses, and real-time monitoring capabilities. Much of PANGA is now upgraded from GPS to GNSS (due in part to ARRA.) PANGA comprises 272 non-PBO stations that extend throughout the Pacific Northwest (Figure 1). This cooperative agreement supported 1) daily processing of these 272 PANGA stations and another ~326 other (PBO, BARD, BARGEN, etc) Cascadia-relevant GPS stations within a consistent, Cascadia-optimized reference frame and the public archiving of those products; 2) network maintenance and collaborative expansion, 3) construction of a dedicated digital radio telemetry system initiated under ARRA, 4) construction and population of a PANGA metadata database, 5) development of real-time Precise Point Positioning for seismic monitoring. Details of each aspect of this are provided below.

Under the current cooperative agreement, the CWU Geodesy Lab currently processes 504 stations deemed relevant to Cascadia tectonics (272 PANGA + 232 PBO) within a consistent, Cascadia-stabilized reference frame and publish their solutions to the web. These activities include daily downloading, public archiving, and processing, with the goal of making the sub-daily and real-time routines used by surveying professionals useful for tectonic monitoring. The resulting denser station spacing afforded by the independent PANGA Network considerably improves slip models and identification of the transient slip itself on the deeper Cascadia subduction zone and provides better-resolved surface strain maps. Where PBO coverage was necessarily bare-bones (for example east of the Cascades) addition of these stations provides tighter bracketing of known seismogenic zones.

The PANGA network has been built and upgraded with robust real-time monitoring in mind, which should allow quicker and better-informed response to very large ground motions both locally and remotely. GNSS rapid earthquake characterization can be critical for quickly and fully determining the energy release of great earthquakes through direct measurement of near-field deformation without problems of instrument saturation. Many efforts have been made by PANGA to further this seismological directive. This past year, for instance, PANGA has been working closely with the USGS to co-locate strong ground motion sensors with coastal GNSS sites (see Appendix A).

Accomplishments & Changes Implemented During Project:

We continue to obtain and archive data from new stations in the region as they become available. Over the course of this award we've added 100's of new sites to our archive and are currently providing solutions for 272 GPS/GNSS sites independent from PBO Network. We continue to collaborate with many Washington, Oregon, and northern California state and county agencies and personnel and private network operators to ensure seamless operations and data product services.

As noted in past reports, coverage around the Olympic-Wallowa line in central Washington is now fairly good, with the structural zone bracketed by several pairs of stations including LMID (Toppenish—new station) and VRNT (Vernita Bridge). Two years ago, we began re-occupation of many campaign sites across these ridges such as WENA on Umtanum Ridge and continue to do so into this spring. Other continuous sites added to our processing include the recently installed stations of the ORGN (Oregon Real Time Geodetic Network) in the Blue Mountains of eastern Oregon, ELGN in Elgin and to the south of the state, LKVW in Lakeview. Since that time we have added the new sites: WACS in Chehalis; PTWA in Tsawassen; WASQ in Snoqualmie; SCCC in Concrete; WABR in Brewster; and WAPO in Poulsbo.

We continue to build upon our independent communications network and have secured several new permits for sites south and east of Mt Adams that will allow an uninterrupted data link from the coast to our lab at Central Washington University in Ellensburg, WA. Last fall we built a new communications link tower on Red Top after receiving a much-anticipated permit with the USDA Forest (see Figure 2). We have constructed a master radio link on top of the science building at CWU that will connect to our network servers via fiber optics.

Using the UNAVCO terrestrial laser scanner based at CWU, we have scanned several representative stations in the area, with the goal of integrating multipath modeling into our processing and in one instance have even built a seismic vault to co-locate with one of these test sites. GNSS data coupled with broadband seismic data will afford the entire frequency spectrum of energy during an event. We also continue development of real time processing strategies and "GPS Cockpit", a Java based tool to display different GPS data products and streams.

Network status:
We archive RINEX files and provide daily solutions for 272 GPS/GNSS distinct stations across the Pacific Northwest (besides those operated by PBO). In real-time these comprise the Washington State Reference Network (WSRN; 118 stations), Oregon Real-time GPS Network (ORGN; 47 stations), various privately run real-time GNSS networks (RGPS; 60 stations), and Western Canada Deformation Array (GSC-NRCan; 25 stations). We also cooperate in efforts to monitor significant manmade structures, including Ross and Boundary Dams and the Alaska Way Viaduct. Our monitoring effort at Howard Hanson is now complete and we are writing the results of this study to be submitted for publication later this spring. We process static data from most of these stations, along with those from PBO and the Cascades Volcano Observatory (CVO; 22 stations) in global and North American reference frames using the Jet Propulsion Laboratory's GIPSY-OASIS software package. The list of current real-time data streams we process is provided below. For the complete list of the receiver antennae and dome code histories for the 272 stations we archive and compute daily solutions for please download the site logs here: http://www.panga.org/data_ftp_pub/sites/logs/.

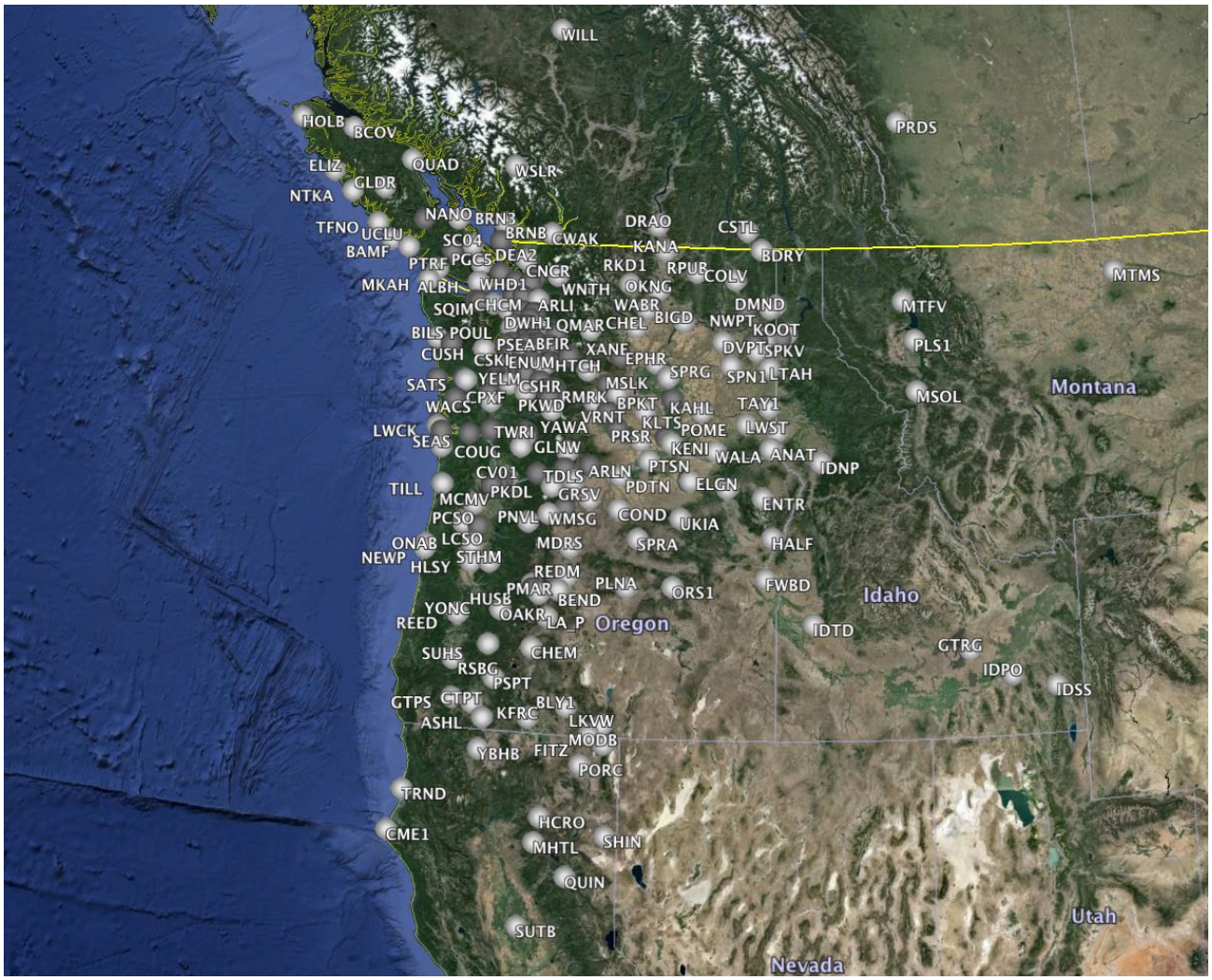


Figure 1. Current PANGA network configuration in Google Maps. See www.panga.org/sites for more station information and ftp://ftp.panga.cwu.edu/pub/sites for map updates.

Figure 2. Clockwise from upper-left; station DEEJ on Olympic Peninsula; radio relay site on Red Top overlooking the Kittitas Valley; view from new ORGN site LKVW in Lakeview, OR; PANGA constructed site RDK1 near Oroville, WA (replaces KANA).

List of 272 PANGA sites with locations and latest antennae/receiver metadata:

Site	Lat	Lon	Rec	Model	Ant	Dome	City	State
ALBH	48.3898	-123.4874	ROGUE	SNR-8000	AOAD/M_T	SCIS	Victoria	BC
ANAT	46.1325	-117.1329	LEICA	GRX1200+GNSS	LEIAT504GG	LEIS	Anatone	WA
ARLI	48.1742	-122.1424	TRIMBLE	NETR3	TRM55971.00	SCIT	Arlington	WA
ARLN	45.7081	-120.1832	LEICA	GRX1200GGPRO	LEIAT504GG	LEIS	Arlington	OR
ASHL	42.1806	-122.6701	LEICA	GRX1200PRO	LEIAT504	LEIS	ASHLAND	OR
ATLI	59.5895	-133.7144	TRIMBLE	NETR8	TRM59800.00	NONE	Atlin	BC
AXIS	47.4042	-120.2848	LEICA	GRX1200GGPRO	LEIAX1202GG	NONE	East Wenatchee	WA
BAMF	48.8353	-125.1351	TRIMBLE	NETRS	TRM29659.00	SCIS	Bamfield	BC
BAYV	48.0020	-122.4578	TRIMBLE	5700	TRM41249.00	NONE	Bayview	WA
BCIT	47.6140	-122.1910	TRIMBLE	NETR9	TRM59800.00	SCIS	Bellevue	WA
BCOV	50.5443	-126.8426	LEICA	GRX1200PRO	LEIAT504	SCIS	Beaver Cove	BC
BDRD	47.2775	-121.7878	TRIMBLE	NETRS	TRM41249.00	NONE	Howard Hansen	WA
BDRH	47.2791	-121.7890	TRIMBLE	NETR5	TRM55971.00	NONE	Howard Hansen	WA
BDRY	48.9866	-117.3502	TPS	NET-G3A	TPSCR.G3	TPSH	Boundary Lake	WA
BEA2	62.4078	-140.8625	ASHTECH	Z-XII3	ASH701945B_M	NONE	Beaver Creek	YT
BELI	48.7568	-122.4771	TRIMBLE	NETR9	TRM55971.00	NONE	Bellingham	WA
BELV	47.6008	-122.1837	TRIMBLE	4700	TRM22020.00+GP	NONE	Bellevue	WA
BEND	44.0571	-121.3151	LEICA	GRX1200PRO	LEIAT504	LEIS	BEND	OR
BFIR	47.6174	-122.1254	TRIMBLE	NETR9	TRM59800.00	SCIS	Bellevue	WA
BIGD	47.9332	-118.9886	TPS	NET-G3A	TPSCR.G3	TPSH	Grand Coulee	WA
BILS	47.5391	-124.2523	TRIMBLE	NETR9	TRM57971.00	SCIT	Queets	WA
BLVU	47.5991	-122.1831	TRIMBLE	4700	TRM33429.00+GP	NONE	Bellevue	WA
BLY1	42.4068	-121.0490	LEICA	GRX1200GGPRO	LEIAT504GG	LEIS	Bly	OR
BPKT	46.8831	-120.3274	TPS	NET-G3A	TPSCR.G3	SCIT	Kittitas	WA
BRCK	62.4143	-140.8604	TRIMBLE	NETR8	TRM59800.00	NONE	Beaver Creek	YT
BRDG	47.2769	-121.7872	TRIMBLE	5700	TRM41249.00	NONE	Howard Hansen	WA
BREW	48.1312	-119.6826	ASHTECH	UZ-12	ASH701945C_M	SCIT	Brewster	WA
BRN3	49.2699	-123.0156	TRIMBLE	NETR5	TRM55971.00	NONE	Burnaby	BC
BRNB	49.2750	-123.0218	TRIMBLE	NETR5	TRM55971.00	TZGD	Burnaby	BC
BSUM	47.5540	-122.1319	TRIMBLE	NETR9	TRM59800.00	SCIS	Newcastle	WA
BTON	45.4858	-122.7973	ASHTECH	Z-XII3	ASH700718B	NONE	Beaverton	OR
CAMI	48.2153	-122.4786	TRIMBLE	5700	TRM41249.00	NONE	Camano Island	WA
CATH	46.1972	-123.3672	TPS	NET-G3A	TPSCR.G3	TPSH	Cathlamet	WA
CH2M	47.5266	-121.8261	LEICA	GRX1200PRO	LEIAX1202	NONE	Snoqualmie	WA
CHCM	48.0106	-122.7758	TPS	NET-G3A	TPSCR.G3	SCIT	Chimacum	WA
CHEL	47.8315	-119.9898	TPS	NET-G3A	TPSCR.G3	TPSH	Chelan	WA
CHEM	43.2243	-121.7858	LEICA	GRX1200GGPRO	LEIAT504GG	LEIS	Chemalt	OR
CHWK	49.1566	-122.0084	TRIMBLE	NETRS	TRM29659.00	SCIS	Chilliwack	BC
CLRS	48.8203	-124.1309	TRIMBLE	NETRS	TRM29659.00	SCIS	Mesachie Lake	BC
CME1	40.4417	-124.3960	ASHTECH	Z-XII3	ASH700829.3	SNOW	Mendocino	CA
CNCR	48.5387	-121.7492	LEICA	GRX1200GGPRO	LEIAX1202	NONE	Concrete	WA
COBO	45.4855	-122.7971	LEICA	GRX1200GGPRO	LEIAT504GG	LEIS	Cobon	OR
COLV	48.5447	-117.9032	TPS	NET-G3A	TPSCR.G3	TPSH	Colville	WA
COND	45.2379	-120.1813	LEICA	GRX1200GGPRO	LEIAT504GG	LEIS	Condon	OR
COUG	46.0592	-122.2607	TPS	NET-G3A	TPSCR.G3	TPSH	Cougar	WA
COUP	48.2171	-122.6848	TPS	NET-G3A	TPSCR.G3	SCIT	Coupeville	WA
CPUD	47.4301	-120.3142	TRIMBLE	NETR9	TRM55971.00	TZGD	Wenatchee	WA
CPXF	46.8400	-122.2560	LEICA	RS500	LEIAT504GG	LEIS	Lagrande	WA

CROK	46.2745	-122.9125	TPS	NET-G3A	TPSCR.G3	TPSH	Castle Rock	WA
CSHR	46.8707	-121.7324	TRIMBLE	NETRS	TRM41249.00	NONE	Longmire	WA
CSKI	47.3803	-122.2355	TPS	NET-G3A	TPSCR.G3	TPSH	Kent	WA
CSTL	49.2581	-117.6573	TPS	NET-G3A	TPSCR.G3	TPSH	Castlegar	OR
CTPT	42.3766	-122.8939	LEICA	GRX1200PRO	LEIAT504	LEIS	Central Point	OR
CUSH	47.4232	-123.2197	TRIMBLE	NETR9	TRM55971.00	NONE	Lake Cushman	WA
CV01	45.6109	-122.4961	JAVAD	TRE_G3TH	TRM29659.00	NONE	Vancouver	WA
CWAK	49.1529	-121.9538	TRIMBLE	NETRS	TRM41249.00	NONE	Chilliwak	BC
DEA1	47.6657	-117.4205	LEICA	GRX1200PRO	LEIAX1202	NONE	Spokane	WA
DEA2	48.7527	-122.4800	LEICA	GRX1200PRO	LEIAX1202	NONE	Bellingham	WA
DEA3	45.5069	-122.6727	LEICA	GRX1200PRO	LEIAX1202	NONE	Portland	OR
DEEJ	47.4687	-123.9259	TPS	NET-G3A	TPSCR.G3	NONE	Amanda Park	WA
DMND	48.1364	-117.1634	TPS	NET-G3A	TPSCR.G3	TPSH	Diamond Lake	WA
DRAO	49.3226	-119.6250	ROGUE	SNR-8000	AOAD/M_T	NONE	Penticton	BC
DVPT	47.6560	-118.1477	TPS	NET-G3A	TPSCR.G3	NONE	Davenport	WA
DWH1	47.7741	-122.0801	JPS	LEGACY	JPSREGANT_DD_E	NONE	Woodinville	WA
ELGN	45.5651	-118.0122	LEICA	GRX1200GGPRO	LEIAR25.R4	LEIT	Elgin	OR
ELIZ	49.8730	-127.1227	Leica	GRX1200PRO	LEIAT504	SCIS	Eliz	BC
ELSR	47.4975	-122.7605	TPS	NET-G3A	TPSCR.G3	SCIT	Bremerton	WA
EMBC	47.2778	-121.7870	TRIMBLE	NETR5	TRM55971.00	NONE	Howard Hansen	WA
ENTR	45.4312	-117.2880	LEICA	GRX1200GGPRO	LEIAT504GG	LEIS	Enterprise	OR
ENUM	47.2062	-121.9555	TRIMBLE	NETR5	TRM55971.00	SCIT	Enumclaw	WA
EMBL	47.2776	-121.7875	TRIMBLE	5700	TRM41249.00	NONE	Howard Hansen	WA
EMBR	47.2780	-121.7865	TRIMBLE	NETR8	TRM55971.00	NONE	Howard Hansen	WA
EPHR	47.3293	-119.5446	TPS	NET-G3A	TPSCR.G3	TPSH	Ephrata	WA
ESM1	47.8034	-122.5691	LEICA	GRX1200PRO	LEIAX1202	NONE	Kingston	WA
FITZ	42.0221	-120.5892	TRIMBLE	R7	TRM41249.00	NONE	Goose Lake	OR
FND1	47.2786	-121.7850	TRIMBLE	NETR5	TRM55971.00	NONE	Howard Hansen	WA
FND2	47.2788	-121.7850	TRIMBLE	NETR5	TRM55971.00	NONE	Howard Hansen	WA
FRFX	47.0079	-121.9594	LEICA	GRX1200GGPRO	LEIAT504GG	NONE	Fairfax Forest	WA
FRID	48.5352	-123.0180	LEICA	GRX1200PRO	LEIAX1202	NONE	Friday Harbor	WA
FTS1	46.2048	-123.9560	ASHTECH	Z-XII3	ASH700829.3	SNOW	Fort Stevens	OR
FWBD	44.2919	-117.2216	LEICA	GRX1200GGPRO	LEIAT504GG	LEIS	Farewell Bend	OR
GLDR	49.6815	-125.8727	LEICA	GRX1200PRO	LEIAT504	NONE	Gold River	BC
GLNW	46.0198	-121.2887	TRIMBLE	5700	TRM41249.00	NONE	Glenwood	WA
GLWD	46.0198	-121.2886	TPS	NET-G3A	TPSCR.G3	SCIT	Glenwood	WA
GOLY	45.8389	-120.8138	TPS	NET-G3A	TPSCR.G3	TPSH	Goldendale	WA
GRCK	48.1435	-117.6645	TPS	NET-G3A	TPSCR.G3	NONE	Grouse Creek	WA
GRMD	46.7954	-123.0226	TPS	NET-G3A	TPSCR.G3	SCIT	Grand Mound	WA
GRP4	48.1946	-122.1272	LEICA	GRX1200PRO	LEIAX1202	NONE	Arlington	WA
GRSV	45.3644	-120.7874	LEICA	GRX1200GGPRO	LEIAT504GG	LEIS	Grass Valley	OR
GTPS	42.4344	-123.2973	LEICA	GRX1200PRO	LEIAT504	LEIS	Grants Pass	OR
GTRG	43.2441	-113.2412	TRIMBLE	NETRS	TRM29659.00	UNAV	Atomic City	ID
GWEN	45.7826	-121.3280	ASHTECH	Z-XII3	ASH700829.3	SNOW	Appleton	WA
HAHD	47.2908	-121.7881	TPS	NET-G3A	TPSCR.G3	SCIT	Palmer	WA
HALF	44.8724	-117.0998	LEICA	GRX1200GGPRO	LEIAT504GG	LEIS	Halfway	OR
HCRO	40.8156	-121.4692	TRIMBLE	NETRS	TRM41249.00	SCIT	Hat	CA
HGP1	47.0193	-122.9210	LEICA	GRX1200PRO	LEIAX1202	NONE	Tumwater	WA
HLSY	44.3775	-123.1091	TRIMBLE	NETR9	TRM57971.00	NONE	Halsey	OR
HOLB	50.6404	-128.1350	ROGUE	SNR-8000	TRM59800.00	SCIS	Holberg	BC
HTCH	47.1915	-120.9657	TRIMBLE	NETRS	TRM41249.00	NONE	Cle Elum	WA
HUSB	44.1195	-121.8494	TRIMBLE	NETRS	TRM29659.00	SCIS	Bend	OR

IDNP	45.9397	-116.1210	TRIMBLE	5700	TRM41249.00	TZGD	Grangeville	ID
IDPO	42.8655	-112.4320	TRIMBLE	NETR9	TRM57971.00	NONE	Pocatello	ID
IDSS	42.6862	-111.5840	LEICA	RS500	LEIAT504	NONE	Soda Springs	ID
IDTD	43.6529	-116.2840	TRIMBLE	NETR5	TRM55971.00	NONE	Boise	ID
INW1	47.7144	-116.9297	LEICA	GRX1200PRO	LEIAX1202	NONE	Post Falls	ID
INW2	48.1879	-117.0298	LEICA	GRX1200PRO	LEIAX1202	NONE	Newport	WA
IWAC	46.3058	-124.0394	JPS	ODYSSEY	TPSCR.G3	TPSH	Ilwaco	WA
JRO1	46.2751	-122.2176	TRIMBLE	5700	JAVRINGANT_DM	SCIS	Castle Rock	WA
KAHL	46.6410	-118.5573	TRIMBLE	NETR5	TRM55971.00	NONE	Kahlotus	WA
KANA	48.9555	-119.4360	TPS	NET-G3A	TPSPG_A1	NONE	Oroville	WA
KENI	46.1978	-119.1586	TPS	NET-G3A	TPSCR.G3	TPSH	Kenniwick	WA
KFRC	42.2241	-121.7838	TRIMBLE	NETRS	TRM41249.00	TZGD	Klamath Falls	OR
KLTS	46.6431	-118.5579	TRIMBLE	NETR5	TRM55971.00	SCIT	Kahlotus	WA
KNTP	47.4251	-122.2575	JPS	ODYSSEY	TPSPG_A1+GP	NONE	Kent	WA
KOOT	47.7707	-116.8096	TRIMBLE	NETR5	TRM55971.00	SCIT	Couer D'Alene	ID
KRMT	47.8028	-122.3209	LEICA	GRX1200PRO	LEIAX1202	NONE	Lynwood	WA
LA_P	43.6646	-121.5060	NONE	NONE	LEIAT504	LEIS	LAPINE	OR
LCSO	44.6343	-123.1066	TRIMBLE	NETR9	TRM57971.00	NONE	Albany	OR
LFLO	43.9835	-124.1077	LEICA	GRX1200PRO	LEIAT504	LEIS	Florence	OR
LINH	47.0003	-120.5384	TPS	NET-G3A	TPSCR.G3	NONE	Ellensburg	WA
LKVW	42.1725	-120.3470	LEICA	GRX1200GGPRO	LEIAT504GG	LEIS	LAKEVIEW	OR
LMID	46.3690	-120.2844	TPS	NETG3	TPSCR.G3	TPSH	Toppenish	WA
LNGB	47.2187	-122.7582	LEICA	GRX1200GGPRO	LEIAT504GG	LEIS	Longbeach	WA
LSIG	47.6951	-121.6895	TRIMBLE	NETR8	TRM55971.00	SCIT	Tolt	WA
LTAH	47.2823	-117.1637	TPS	NET-G3A	TPSCR.G3	SCIT	Latah	WA
LWCK	46.2778	-124.0536	TPS	NET-G3A	TPSCR.G3	SCIT	Ilwaco	WA
LWST	46.3731	-117.0021	TRIMBLE	NETR5	TRM55971.00	NONE	Lewiston	ID
MCMV	45.1973	-123.1331	ASHTECH	UZ-12	ASH700228A	NONE	McMinnville	OR
MDRS	44.6640	-121.1304	LEICA	GRX1200GGPRO	LEIAT504GG	LEIS	Madras	OR
MHTL	40.4456	-121.5596	TRIMBLE	NETRS	TRM41249.00	SCIS	Timberline Lodge	OR
MKAH	48.3707	-124.5888	TPS	NET-G3A	TPSCR.G3	TPSH	Makah	WA
MODB	41.9023	-120.3030	TRIMBLE	NETRS	ASH701945B_M	SCIT	Pleasant Canyon	CA
MONT	46.9828	-123.6035	TPS	NET-G3A	TPSCR.G3	TPSH	Montesano	WA
MRSD	46.7851	-121.7417	JAVAD	TRE_G3TH	TRM29659.00	SCIS	Ashford	WA
MSLK	47.1306	-119.2737	TPS	NET-G3A	TPSPG_A1+GP	NONE	Moses Lake	WA
MSOL	46.9294	-114.1090	TRIMBLE	NETR5	TRM57971.00	NONE	Missoula	MT
MTFV	48.2274	-114.3270	TRIMBLE	5700	TRM41249.00	NONE	Kalispell	MT
MTMS	48.5409	-109.6870	TRIMBLE	NETRS	TRM41249.00	NONE	Havre	MT
MUIR	46.8354	-121.7327	TRIMBLE	NETRS	TRM41249.00	NONE	Ashford	WA
NANO	49.2948	-124.0865	LEICA	GRX1200GGPRO	LEIAT504GG	LEIS	Nanoose Bay	BC
NEWP	44.5850	-124.0619	TRIMBLE	4000SSI	ASH700936E_C	UNAV	Newport	OR
NINT	47.4951	-121.7969	TRIMBLE	NETR5	TRM55971.00	NONE	North Bend	WA
NTKA	49.5924	-126.6166	LEICA	GRX1200PRO	LEIAT504	SCIS	Nootka Island	BC
NWIS	48.4191	-122.6702	TRIMBLE	4700	TRM29659.00	NONE	Deception Pass	WA
NWPT	48.1776	-117.0480	TPS	NET-G3A	TPSCR.G3	TPSH	New Port	WA
OAKR	43.7383	-122.4450	LEICA	GRX1200GGPRO	LEIAT504GG	LEIS	Oakridge	OR
OBSR	46.8997	-121.8153	TRIMBLE	NETRS	TRM41249.00	NONE	Ashford	WA
OCEN	46.9522	-124.1593	TRIMBLE	NETR5	TRM55971.00	SCIT	Ocean Shores	WA
ODOT	44.8967	-123.0007	LEICA	GRX1200GGPRO	LEIAT504GG	LEIS	Salem	OR
OKNG	48.3733	-119.5511	TPS	NET-G3A	TPSCR.G3	TPSH	Okanagon	WA
OLAR	46.9608	-122.9082	TPS	NET-G3A	TPSCR.G3	SCIT	Olympia	WA

OLMP	47.0447	-122.8950	TPS	NET-G3A	TPSCR.G3	TPSH	Olympia	WA
ONAB	44.5143	-124.0741	LEICA	GRX1200GGPRO	LEIAT504GG	LEIS	Ona Beach	OR
ORS1	44.1642	-119.0590	TRIMBLE	NETRS	ASH701945E_M	SCIT	Seneca	OR
OTHL	46.8225	-119.1678	TPS	NET-G3A	TPSCR.G3	TPSH	Othello	WA
OTIS	48.4178	-122.3365	TRIMBLE	4700	TRM22020.00+GP	NONE	Mt Vernon	WA
OYLR	47.4746	-122.2047	TRIMBLE	NETR3	TRM55971.00	TZGD	Renton	WA
PCSO	44.9190	-123.3278	TRIMBLE	NETR5	LEIAT504	LEIS	DALLAS	OR
PDTN	45.6659	-118.7569	TPS	NET-G3A	TPSCR.G3	NONE	Pendleton	OR
PDXA	45.5968	-122.6092	TRIMBLE	NETR9	TRM55971.00	TZGD	Portland	OR
PDXB	45.5664	-122.5815	JPS	ODYSSEY	TPSCR3_GGD	CONE	Portland	OR
PER1	47.9816	-122.2081	LEICA	GRX1200PRO	LEIAX1202	NONE	Everett	WA
PFLD	47.8985	-122.2817	TRIMBLE	NETR9	TRM55971.00	SCIT	Everett	WA
PGC5	48.6483	-123.4511	LEICA	CRS1000	LEIAT504	NONE	North Saanich	BC
PKDL	45.5182	-121.5636	LEICA	GRX1200GGPRO	LEIAT504GG	LEIS	Parkdale	OR
PKWD	46.5997	-121.6769	TPS	NET-G3A	TPSCR.G3	TPSH	Packwood	WA
PLMN	46.7339	-117.1930	TPS	NET-G3A	TPSCR.G3	TPSH	Pullman	WA
PLNA	44.1319	-119.9666	LEICA	GRX1200GGPRO	LEIAT504GG	LEIS	Paulina	OR
PLS1	47.6637	-114.1130	ASHTECH	Z-XII3	ASH700829.3	SNOW	Polson	MT
PMAR	43.9907	-121.6867	JAVAD	TRE_G3TH	JAVRINGANT_DM	SCIS	Bend	OR
PNCL	48.1014	-123.4152	TPS	NET-G3A	TPSCR.G3	TPSH	Port Angeles	WA
PNDL	45.6695	-118.7915	TPS	NET-G3A	TPSCR.G3	TPSH	Pendleton	OR
PNHG	46.8590	-121.6426	TRIMBLE	NETRS	TPSPG_A1+GP	NONE	Ashford	WA
PNVL	44.9999	-121.9999	LEICA	GRX1200GGPRO	LEIAT504GG	LEIS	Prineville	OR
POME	46.4799	-117.6316	LEICA	GRX1200+GNSS	LEIAT504GG	LEIS	Pomeroy	WA
PORC	41.5995	-120.7432	TRIMBLE	5700	TRM41249.00	NONE	Porcupine Rim	CA
POUL	47.7546	-122.6672	SPP	GEOTRACER100	TRM33429.00+GP	NONE	Poulsbo	WA
PRDS	50.8713	-114.2930	TPS	NET-G3A	AOAD/M_T	NONE	Calgary	AB
PRDY	47.3913	-122.6094	LEICA	GRX1200GGPRO	LEIAT504GG	LEIS	Purdy	WA
PRSR	46.2156	-119.7908	TPS	NET-G3A	TPSCR.G3	NONE	Prosser	WA
PSEA	47.4513	-122.3201	LEICA	GRX1200PRO	LEIAX1202	NONE	Seattle	WA
PSPT	42.7548	-122.4894	LEICA	GRX1200PRO	LEIAT504	LEIS	Prospect	OR
PTAA	48.1168	-123.4943	TPS	NET-G3A	TPSCR.G3	SCIT	Port Angeles	WA
PTAL	49.2563	-124.8610	TRIMBLE	NETRS	TRM29659.00	SCIS	Port Alberni	BC
PTRF	48.5443	-124.4131	TRIMBLE	NETRS	TRM29659.00	SCIS	Port Renfrew	BC
PTSN	45.9391	-119.6097	LEICA	GRX1200+GNSS	LEIAT504GG	LEIS	Patterson	WA
PTWA	49.0061	-123.0825	LEICA	GRX1200GGPR	GPPNULLANTENNA	NONE	Tsawassen	WA
QMAR	47.7750	-120.9655	TRIMBLE	NETR9	TRM55971.00	TZGD	Stevens Pass	WA
QUAD	50.1325	-125.3308	TRIMBLE	NETRS	TRM29659.00	SCIS	Quadra Island	BC
QUIN	39.9745	-120.9450	ROGUE	SNR-8000	ASH701945E_M	NONE	Quincy	CA
REDM	44.2597	-121.1478	TRIMBLE	NETRS	TRM29659.00	NONE	Redmond	OR
REED	43.7010	-124.1075	LEICA	GRX1200GGPRO	LEIAT504GG	LEIS	Reedsport	OR
RICH	46.2772	-119.2774	TRIMBLE	NETR5	TRM55971.00	NONE	Richland	WA
RKD1	48.9643	-119.4125	TPS	NET-G3A	TPSCR.G3	SCIT	Oroville	WA
RMRK	46.7487	-120.7924	LEICA	GRX1200+GNSS	LEIAT504GG	LEIS	Naches	WA
ROSS	48.8336	-87.5193	TRIMBLE	NETRS	TRM29659.00	SCIT	Concrete	WA
RPT1	47.3875	-122.3750	ASHTECH	Z-XII3	ASH700829.3	SNOW	Robinson Point	WA
RPUB	48.6492	-118.7339	TPS	NET-G3A	TPSCR.G3	TPSH	Republic	WA
RSBG	43.2349	-122.6407	LEICA	GRX1200+GNSS	LEIAT504GG	LEIS	Roseburg	OR
RYMD	46.6841	-123.7304	TPS	NET-G3A	TPSCR.G3	TPSH	Raymond	WA
SAMM	47.5398	-122.0332	TPS	NET-G3A	TPSCR.G3	TPSH	Issaquah	WA
SATS	46.9654	-123.5402	TRIMBLE	4000SSi	TRM29659.00	NONE	Montesano	WA
SC04	48.9232	-123.7041	TRIMBLE	NETRS	TRM29659.00	SCIS	Chemainus	BC

SEAS	45.9838	-123.9216	LEICA	GRX1200GGPRO	LEIAT504GG	LEIS	Seaside	OR
SEDK	48.5041	-122.2389	LEICA	GRX1200PRO	LEIAX1202	NONE	Sedro Wooley	WA
SHIN	40.5917	-120.2250	TRIMBLE	NETRS	TRM29659.00	SCIS	Litchfield	CA
SKMA	45.6942	-121.8839	TPS	NET-G3A	TPSCR.G3	TPSH	Stevenson	WA
SMAI	47.5235	-122.3450	TRIMBLE	NETR3	TRM57971.00	NONE	Seattle	WA
SNOQ	47.3913	-121.3882	LEICA	GRX1200+GNSS	LEIAT504GG	LEIS	Snoqualmie Pass	WA
SNRS	46.9146	-121.6435	JAVAD	TRE_G3TH	JAVRINGANT_DM	SCIS	Ashford	WA
SPKN	47.6276	-117.5025	TPS	NET-G3A	TPSCR.G3	SCIT	Spokane	WA
SPKV	47.6774	-117.2715	LEICA	GRX1200GGPRO	LEIAT504	LEIS	Spokane	WA
SPN1	47.5183	-117.4240	ASHTECH	Z-XII3	ASH700829.3	SNOW	Spokane	WA
SPRA	44.8267	-119.7763	LEICA	GRX1200+GNSS	LEIAT504GG	LEIS	Spray	OR
SPRG	47.3098	-117.9753	TRIMBLE	NETR9	TRM55971.00	SCIT	Sprague	WA
SPWY	47.2773	-121.7880	TRIMBLE	NETR5	TRM55971.00	NONE	Howard Hansen	WA
SQIM	48.0823	-123.1020	LEICA	GRX1200PRO	LEIAX1202	NONE	Sequim	WA
SSHO	47.6822	-122.3151	TRIMBLE	NETR9	TRM57971.00	NONE	Seattle	WA
STAR	46.8508	-121.7938	TRIMBLE	NETRS	TPSPG_A1+GP	UNKN	Ashford	WA
STHM	44.3961	-122.7342	TRIMBLE	NETR9	TRM57971.00	NONE	Sweet Home	OR
SUHS	42.9869	-123.3288	LEICA	GRX1200GGPRO	LEIAT504GG	LEIS	Myrtle Creek	OR
SUTB	39.2058	-121.8206	TRIMBLE	NETRS	ASH700936C_M	SCIS	Colusa	CA
TACO	47.2289	-122.4711	TPS	NET-G3A	TPSCR.G3	TPSH	Tacoma	WA
TAY1	46.7146	-117.1762	LEICA	GRX1200PRO	LEIAX1202	NONE	Pullman	WA
TDLS	45.6077	-121.1295	LEICA	GRX1200GGPRO	LEIAT504GG	LEIS	The Dalles	OR
TFNO	49.1541	-125.9078	TRIMBLE	NETRS	TRM59800-00	SCIS	Tofino	BC
TGUA	46.2192	-122.1923	JAVAD	TRE_G3TH	JAVRINGANT_DM	SCIS	Castle Rock	WA
THAR	46.2752	-122.1740	JAVAD	TRE_G3T	JAVRINGANT_DM	SCIS	Cougar	WA
THUN	47.1058	-122.2884	LEICA	GRX1200GGPRO	LEIAT504GG	LEIS	Puyallup	WA
TILL	45.4550	-123.8307	LEICA	GRX1200GGPRO	LEIAT504GG	LEIS	Tillamook	OR
TMGO	40.1309	-105.2330	ROGUE	SNR-8000	ASH700936E	NONE	Table Mountain	CO
TRI1	47.7087	-122.1874	LEICA	GRX1200PRO	LEIAX1202	NONE	Kirkland	WA
TRND	41.0539	-124.1509	TRIMBLE	NETRS	TRM29659.00	UNAV	Trinidad Head	CA
TSTU	46.2368	-122.2240	JAVAD	TRE_G3TH	JAVRINGANT_DM	SCIS	Castle Rock	WA
TUMW	46.9842	-122.9121	TRIMBLE	NETR5	TRM55971.00	TZGD	Tumwater	WA
TWIW	46.2129	-122.1587	JAVAD	TRE_G3TH	JAVRINGANT_DM	SCIS	Castle Rock	WA
TWR1	47.2767	-121.7870	TRIMBLE	NETR5	TRM55971.00	NONE	Howard Hansen	WA
TWRI	46.1979	-122.2119	JAVAD	TRE_G3TH	JAVRINGANT_DM	SCIS	Castle Rock	WA
UCLU	48.9256	-125.5416	ROGUE	SNR-8000	TRM29659.00	SCIS	Ucluelet	BC
UFDA	47.7550	-122.6673	TPS	NETG3	TPSCR.G3	TPSH	Poulsbo	WA
UKIA	45.1327	-118.9364	LEICA	GRX1200GGPRO	LEIAT504GG	LEIS	Ukiah	OR
V096	47.6016	-122.3362	TRIMBLE	NETRS	TRM41249.00	NONE	Seattle	WA
V102	47.6005	-122.3357	TRIMBLE	NETRS	TRM41249.00	NONE	Seattle	WA
VCWA	45.6176	-122.5160	TPS	NET-G3A	TPSCR.G3	TPSH	Vancouver	WA
VERN	48.4178	-122.3371	LEICA	GRX1200GGPRO	LEIAX1202	NONE	Mt. Vernon	WA
VRNT	46.6368	-119.7320	LEICA	GRX1200+GNSS	LEIAT504GG	LEIS	Vernita	WA
WABR	48.1004	-119.7799	LEICA	GRX1200PRO	LEIAT502	NONE	Brewster	WA
WACS	46.6754	-122.9696	LEICA	GR10	LEIAR10	NONE	Chehalis	WA
WAEV	47.9816	-122.2077	LEICA	GR10	LEIAR10	NONE	Everett	WA
WALA	46.0915	-118.2581	LEICA	GRX1200+GNSS	LEIAT504GG	LEIS	Walla	WA
WAMC	45.2238	-121.2736	LEICA	GRX1200GGPRO	LEIAT504GG	LEIS	Wamic	OR
WCM1	47.5411	-122.6359	ASHTECH	Z-XII3	ASH700718B	NONE	Port Orchard	WA
WEEZ	47.9768	-122.2047	TRIMBLE	NETR3	TRM55971.00	NONE	Everett	WA
WHD1	48.3127	-122.6960	ASHTECH	Z-XII3	ASH700829.3	SNOW	Whidbey Island	WA

WHIT	60.7505	-135.2220	TPS	NET-G3A	AOAD/M_T	NONE	Whitehorse	YT
WHIT	60.7505	-135.2221	TPS	NET-G3A	AOAD/M_T	NONE	Whitehorse	BC
WIFC	44.0596	-121.8175	TRIMBLE	5700	TRM41249.00	SCIS	Bend	OR
WIFR	44.0596	-121.8175	TRIMBLE	NETRS	TRM41249.00	NONE	Bend	OR
WILL	52.2369	-122.1678	TRIMBLE	NETR9	TRM59800.00	SCIS	Williams	BC
WMSG	45.1312	-121.5972	LEICA	GRX1200GGPRO	LEIAT504GG	LEIS	Government Camp	OR
WNTH	48.4632	-120.1729	TPS	NET-G3A	TPSCR.G3	TPSH	Winthrop	WA
WOST	50.2123	-126.6047	LEICA	GRX1200PRO	LEIAT504	NONE	Woss	BC
WOST	50.2124	-126.6050	LEICA	GRX1200PRO	LEIAT504	NONE	Woss	BC
WSLR	50.1265	-122.9212	TRIMBLE	NETRS	AOAD/M_T	SCIS	Whistler	BC
XANE	47.4448	-120.3660	TPS	NET-G3A	TPSCR.G3	TPSH	Wenatchee	WA
YAKI	46.6049	-120.5050	TRIMBLE	NETR5	TRM55971.00	NONE	Yakima	WA
YAWA	46.6049	-120.5050	TRIMBLE	4000SSI	TRM22020.00+GP	NONE	Yakima	WA
YBHB	41.7316	-122.7110	TRIMBLE	NETRS	ASH700936C_M	SCIT	Yreka	CA
YELM	46.9487	-122.6057	LEICA	GRX1200GGPRO	LEIAT504GG	LEIS	Yelm	WA
YONC	43.6341	-123.2982	LEICA	GRX1200GGPRO	LEIAT504GG	LEIS	Drain	OR
ZSE1	47.2869	-122.1880	NOV	WAASGII	MPL_WAAS_2225NW	NONE	Seattle	WA

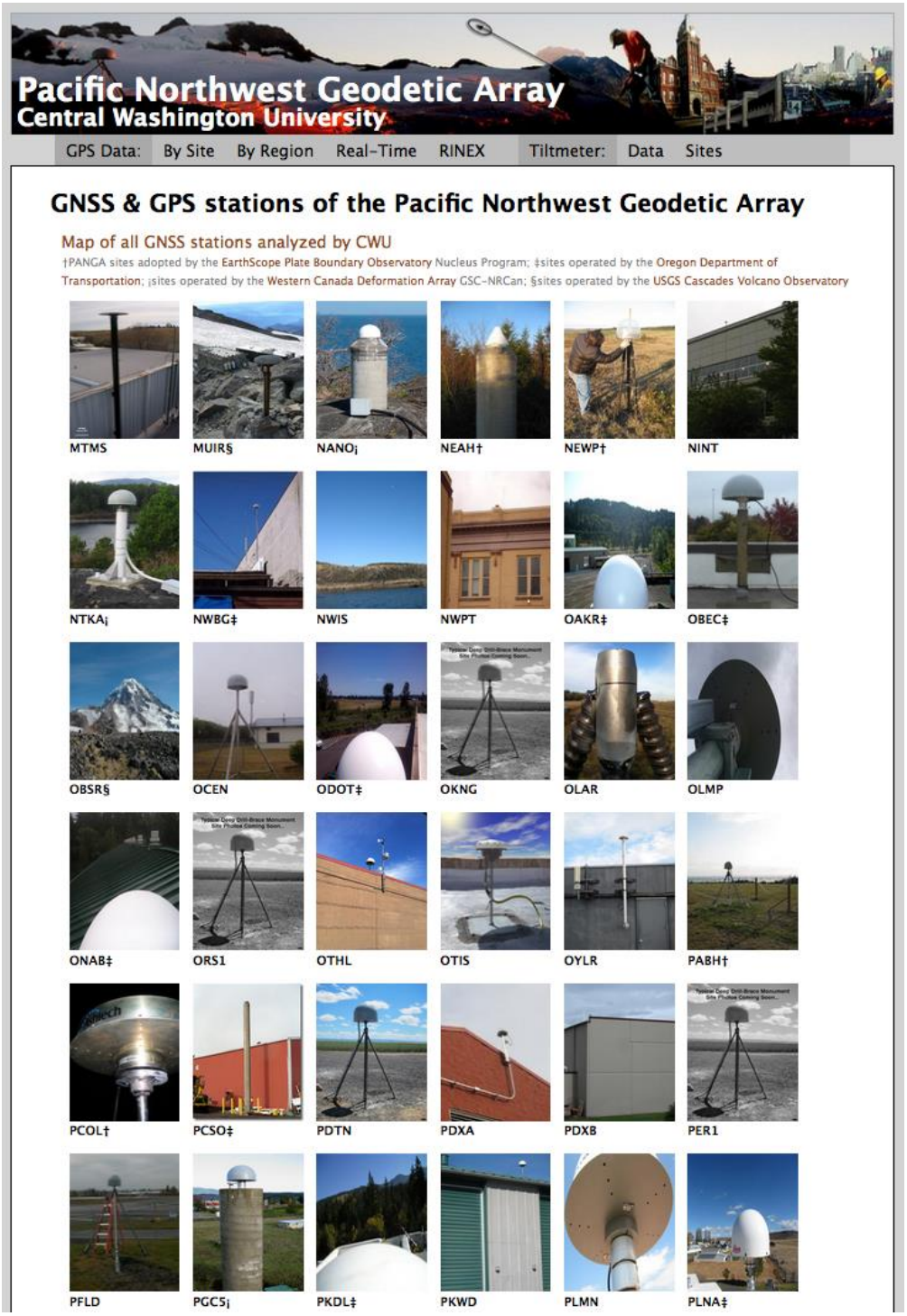
Data Management practices:

We distribute compacted RINEX on our ftp site at both the original sampling rate (1 second in many cases) and decimated to 30 seconds. The 30-second data is generally also picked up by SOPAC. We can provide real time data for most stations in Washington and some in Oregon by request. This requires an NTRIP user name and password to be set up with us.

We continue to work on providing PANGA metadata via the web. We now have IGS metadata pages linked off the home PANGA page containing time-dependent receiver and antenna types, monument information, GMT station map files, kml files for Google Earth showing PANGA stations, and the like. The metadata database products used in our PANGA GPS processing are available via web access. This database uses SQLite, which reads and writes to a binary file and avoids a server. We still anticipate the implementation of a CGI-interface to SQLite that will enable users to input a station name and receive all known metadata relevant to that station. We continue to maintain our Google Maps PANGA station page and all other metadata sources we currently offer. Metadata we maintain used in the processing (typically our best synthesis of rinex headers, site logs, and other available information) can be found at: http://www.panga.org/data_ftp_pub/sites/logs/. These are IGS standard log files of the most recent upgrades in antennae and receivers we process. We maintain over 110 of these site logs while the others are imported from other network operators such as the ORGN, GSC-NRCan, and CVO. Maintaining these log files to ensure quality time-series requires constant communication with our cooperating partners.

Time Series

For time series, go to http://www.panga.cwu.edu
In the top (grey) toolbar, click “by Site”. When changing sites, make sure to allow time for the new images to load. Click “Data” to the right of the plots for the source data. Plots can also be customized via the link to the upper right. “by Region” shows stacked time series (particularly useful when looking for transients). These time series come from two sources: routing PBO processing and combination where available, otherwise from our internal “PANGA” processing, which is sometimes less up to date. “Site Photos” shows an alphabetized list of icons for all 336 GPS/GNSS sites we process (PANGA and PBO Nucleus). Most have specific site photos. We are currently updating these as more photos become available (below).

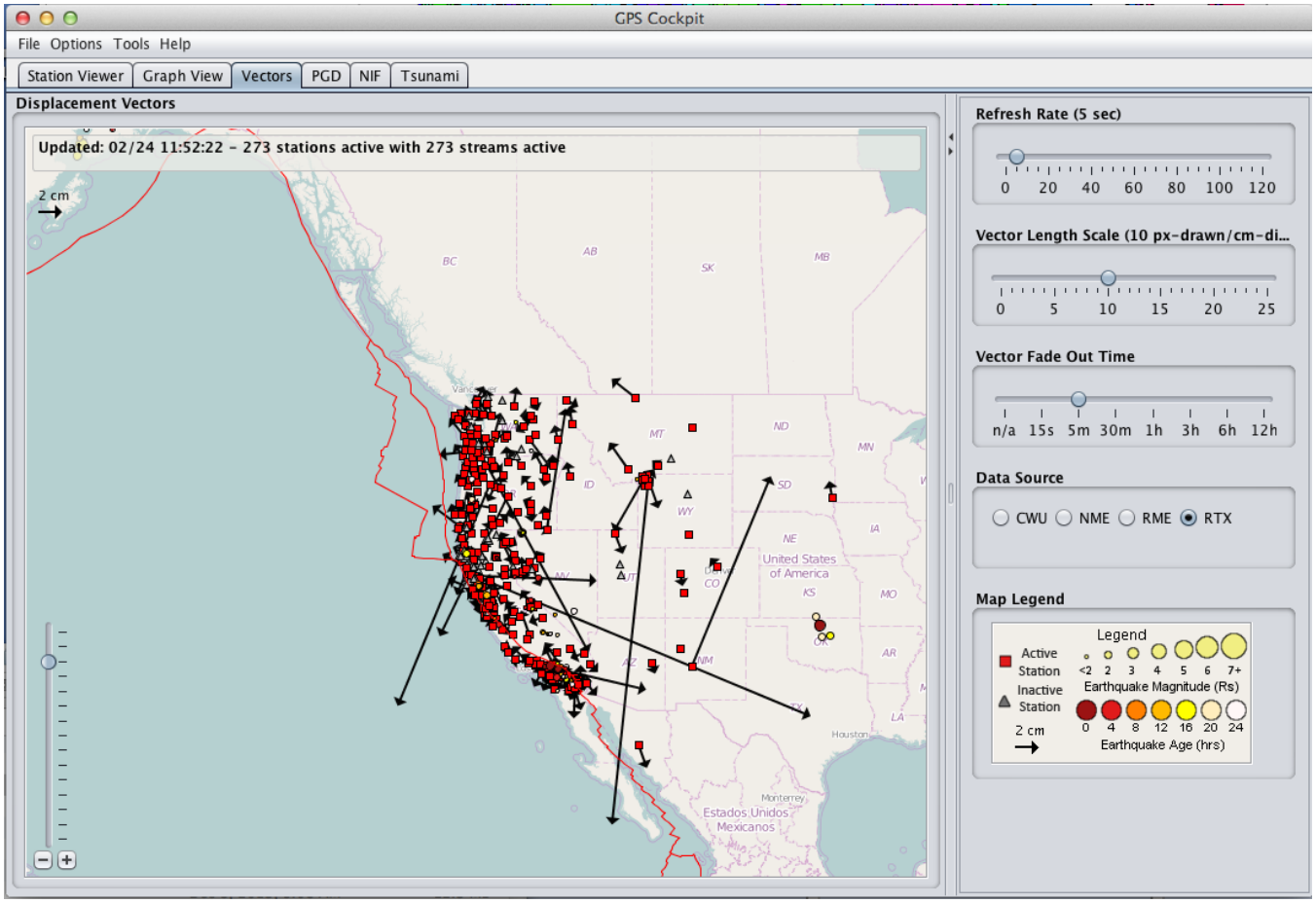


Real-time Position Analysis

Due to our collaboration with the numerous federal, state, county and private groups involved with RTK surveying, the PANGA network was built and has been maintained with robust real-time monitoring in mind. This has encouraged us to develop processing and earthquake estimation routines to allow quicker and better-informed response to very large ground motions both locally and remotely. “GNSS seismology” is critical for quickly and fully determining the energy release of great earthquakes because it directly measures ground motions, without problems of instrument saturation. See Appendix A for coastal PANGA GNSS sites slated to be collocated with strong ground motion sensors.

This is not a trivial task: the operational difference between traditional GPS, which relies on static *files* downloaded daily, versus real-time GPS, which uses continuous *streams* of data, is vast. Nearly all software has been written from scratch, since there are no existing tools available to do what we need done. We have made much progress on all fronts, including writing software such as Kalman filters to Q/C incoming streams of phase and range data by flagging and fixing cycle-slips; the processing of those data into station positions in real time using modifications to GIPSY and employing continuous streams of satellite clock and orbit corrections streamed in from processing centers at the IGS and DLR; handling the resultant streams of station positions into a local database (what we call the Aggregator); and servers to disseminate those position streams to clients out on the internet.

We have continued to develop our data viewer and navigation program, GPS Cockpit, that capture the real-time position streams from the Aggregator and displays a variety of useful earthquake-related data streams, including peak-ground deformation, vector maps of apparent position, finite-fault estimates of slip along the megathrust, and tsunami excitation. We have increased the number of stations available through our GPS Cockpit software to over 300 sites.



GPS Cockpit

Problems encountered and useful lessons:

Some of our time series have not yet recovered from the effects of changes to JPL orbit products and the numerous equipment changes over the last couple years, and the processing and sometimes reprocessing to weed out spurious steps these entail. We have traditionally offered our PANGA time series in ITR2000 and ITRF2005 but in 2008 switched to providing them in SNARF. However, with the August 2009 termination of old-format style JPL products we switched back to providing time series in ITRF2005. We have completed a reprocessing of all PANGA data back through 1993 with the new-format JPL products, and now provide both ITRF2005 and SNARF time series. We are currently reprocessing the entire PANGA plus PBO network across Cascadia with updated site metadata and all within a single consistent orbital parameter space. These results will be published on our website next month.

Improving telemetry remains a primary goal but is a slow and time-consuming business. For example, we had one permit for a key radio site in process for two years now, but were informed that a decision was pending two studies, a review or two, and the weather. This permit was finally approved last fall and the communications tower built within the week. As a stopgap we have with our partners installed 3G/4G cellular gateways at several previously problematic sites (at least one of which had no cell coverage at all when originally installed) such as GLWD in Glenwood and LWCK in Ilwaco, WA and are currently in the process of rerouting data comms in Oroville, WA for the National CORS site we built, RDK1. Typically local surveyors, in exchange for network RTK client licenses, pay for the recurring data service costs. Additional priorities for upgrades are sites that need to push data over DSL connections or agency intranets. Lack of stable IP addresses tends to be the main issue.

There were several instances of outages due to server and/or commercial software problems during the year. In addition to interruptions in streaming, these also in some cases resulted in considerable gaps in our rinex archive for some stations. We need to continue as much as possible to move toward a system where we receive data streams as directly as possible from the stations and simplify the processing.

While working toward rapid, centralized processing and measurement of earthquakes and other earth-shaking events is our immediate goal, it may be that a more reliable alternative for early warning be more decentralized. Rather than rely on any sort of two-way communication across the region, one can envision a scenario where strategically located seismometers and “smart” GPS receivers (e.g., the Trimble NetR9) be enabled to sound their own tsunami or other alarm given sufficiently alarming inputs (for example over 1 meter of ground motion).

Presentations for further reference:

http://www.unavco.org/community/meetings-events/2012/sciworkshop12/plen4_melbourne.pptx
http://fallmeeting.agu.org/2012/eposters/eposter/g53b-1148/

Relevant PANGA publications during award period:

Real-time Monitoring of Tectonic Displacements in the Pacific Northwest through an Array of GPS Receivers
Răzvan Popovici, Răzvan Andonie, Walter M. Szeliga, Timothy I. Melbourne, Craig W. Scrivner
International Journal of Computers Communications & Control
ISSN 1841-9836, 10(1):78-88, February, 2015

Clustering and Visualization of Geodetic Array Data Streams using Self-Organizing Maps
Răzvan Popovici, Răzvan Andonie, Walter M. Szeliga, Timothy I. Melbourne, Craig W. Scrivner

Science News: Quakes in Slo-Mo
ETS Discussion featuring PANGA photos and research
Science News, March 23, 2013

2012 Haida Gwaii Quake: Insight Into Cascadia’s Subduction Extent
Walter Szeliga
EOS, TRANSACTIONS, AMERICAN GEOPHYSICAL UNION, Vol. 94, No. 9, 26 February 2013

Slow-slip phenomena in Cascadia from 2007 and beyond: A review
Gomberg, J., and the Cascadia 2007 and Beyond Work Group
Geological Society of America Bulletin, July/August 2010
March 29, doi10.1130/B30287.1, 2010

Future Cascadia megathrust rupture delineated by episodic tremor and slip
Chapman, J., T. Melbourne
Geophysical Research Letters, vol.36, L22301, doi:101029/2009GL040465, 2009

Appendix A: Potential Coastal PANGA GNSS sites to be collocated with strong ground motion sensors

LWCK: Lewis and Clark Interpretive Center

PTAA: Port Angeles

DEEJ: Amanda Park

OLAR: Olympia Airport

OCEN: Ocean Shores